GEOPHYSICAL SURVEYS FOR GROUND WATER EVALUATION ROYAL COAST DEVELOPMENT CORPORATION GOLF COURSE ISLAND OF HAWAII

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GROUND WATER EVALUATION
ROYAL COAST DEVELOPMENT CORPORATION GOLF COURSE
ISLAND OF HAWAII

Prepared For:

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(BGI Project #90042)

Table of Contents

1.0 INTRODUCTION

Time domain electromagnetic (TDEM) geophysical surveys were performed between September 7 to September 17, 1990 on the Island of Hawaii by Blackhawk Geosciences, Inc. (BGI) for Tom Nance Water Resources Engineering. The surveys were conducted to assist in the evaluation of the ground water resources at the proposed Royal Coast Development Corporation (RCDC) Golf Course near Captain Cook.

The primary objective of the geophysical survey was to determine the elevation and thickness of the lens of fresh water floating on salt water. The generalized objectives for utilizing geophysical surveys for ground water evaluations on volcanic islands are illustrated in Figure 1-1. The volcanic rocks are generally highly permeable and this allows rainwater to percolate with little impedance directly downward through the island mass. The fresh water in these island settings is generally found in two environments:

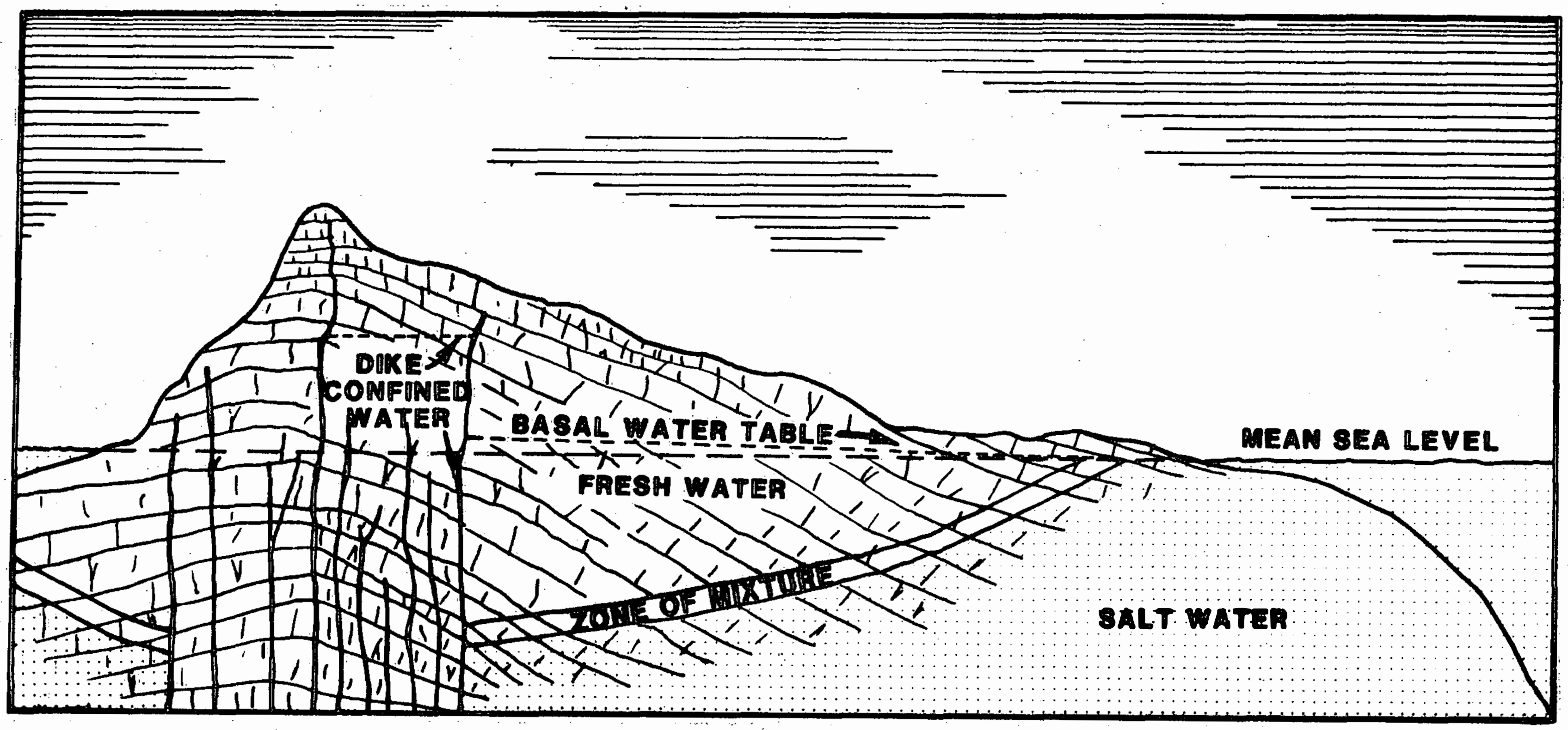
1. Dike-confined waters. Typically, above the rift zone intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

2. Basal fresh water. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a delicate balance is reached where a lens of fresh water floats on sea water. In cases of hydrostatic equilibrium, the Ghyben-Herzberg relation states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

The impetus for using geophysics is that the cost of a geophysical sounding is about one-thousandth the cost of completing a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

Because the electrical resistivity of rock formations is highly dependent upon the salinity of ground water, electrical surface geophysical techniques can map the depth to salt water, and the thickness of the fresh water lens can then be estimated using the Ghyben-Herzberg principle.

The specific geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042

FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION PROCEDURES

2.1 GENERAL

The TDEM survey was accomplished by a three man crew consisting of two BGI personnel and one local temporary field helper. The locations of the sounding sites were determined during consultation with RCDC personnel and their consulting hydrologist. TDEM soundings were initially made at or near the 800 ft to 1,000 ft level, and several other soundings were acquired at higher elevations north and east of the RCDC property. Figure 2-1 shows the sounding locations.

Transmitter loops varied in size according to the depth of investigation needed and available property and road access. At elevations from 800 ft to 1,000 ft, transmitter loops of 750 ft by 850 ft and 1,000 ft by 1,000 ft were used to detect the salt water interface. One sounding above the 1,600 ft elevation level was acquired with a 1,000 ft by 1,000 ft transmitter loop. After site checking some additional areas (uphill of Hwy 160) were deemed not appropriate for TDEM measurements because of the excessive amount of surrounding power lines and associated culture which can deteriorate data quality.

During the four days of field work a total of 6 soundings were acquired. Sounding locations were surveyed using a compass and hip-chain from known landmarks (i.e., rock walls, roads) located on the field maps. Sounding center elevations were measured using an altimeter in the field and checked with detailed property and USGS maps. A daily log of field activities during this survey is given in Table 2-1.

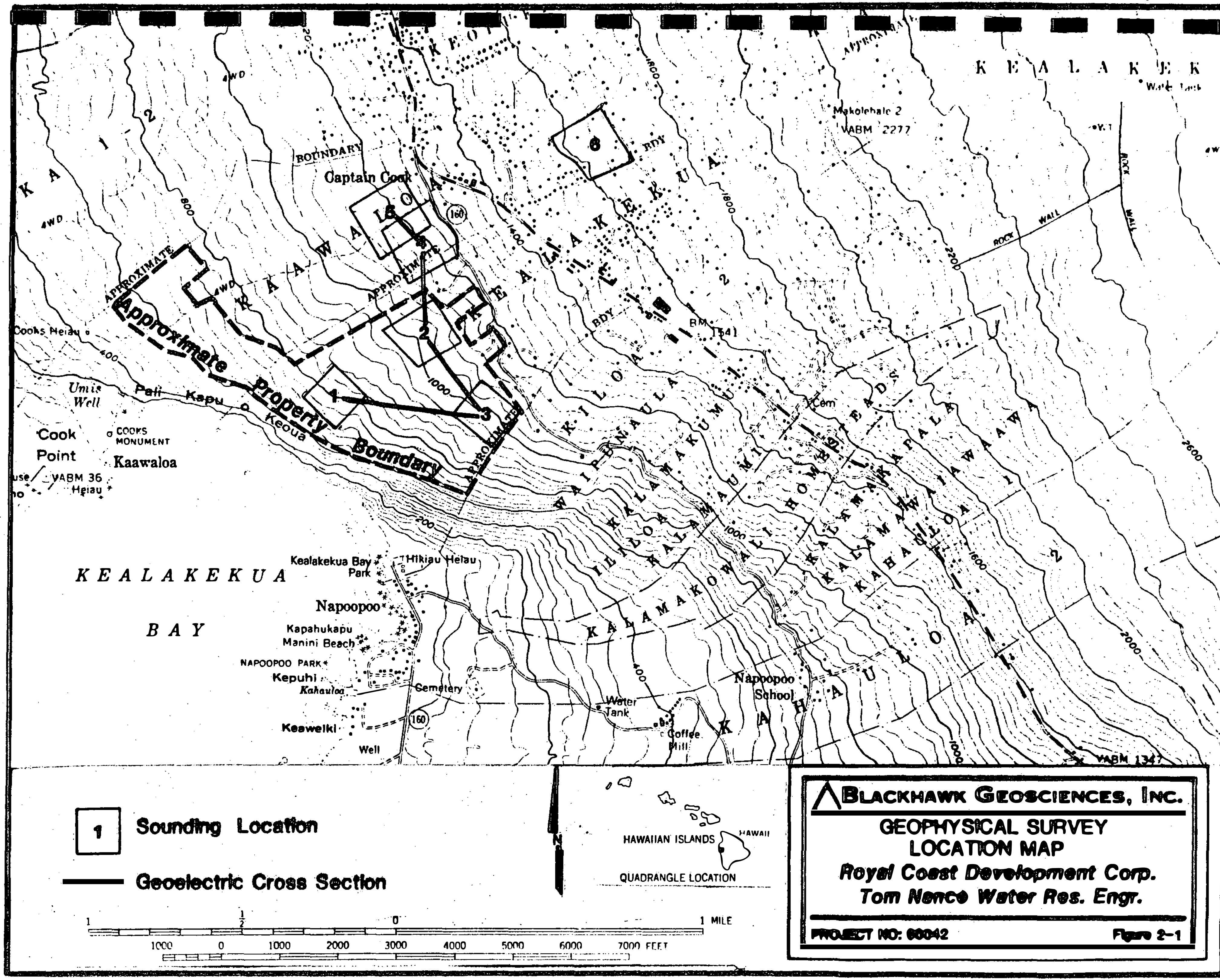
Table 2-1. Daily log of field activities

Date (1990)	Activity
September 6	Mobilize from Denver, CO to Kailua-Kona, HI in conjunction with other surveys.
September 7	Meet with RCDC field representative and conduct field reconnaissance of golf course property for sounding sites. Acquire data on sounding 1.
September 8	RCDC property data on soundings 2 and 3.
September 13	Layout transmitter loop for sounding 4 north of RCDC property in PM. One-half day of field work.
September 14	Reconnaissance with RCDC field representative for other sounding sites north and east of property. Data on sounding 4. One-half day of field work.
September 16	Data on sounding 5. One-half day of field work.
September 17	Data on sounding 6. One-half day of field work.
September 19	Demobilize equipment and BGI personnel.

(September 9 through 12, and September 15 and 18 were days of field work on other Hawaii jobs).

2.2 PROCEDURES

The Geonics EM-37 TDEM system was utilized on this survey. The system basically consists of a transmitter and a receiver. The transmitter loop is constructed of 10 to 12 gauge insulated copper wire. The wire is laid on the ground surface in a square loop varying in size, depending upon the required depth of investigation (larger loop sizes for deeper measurement). A transmitter and motor generator are connected into the non-grounded loop at one corner. A time-varying current is pulsed through the wire at two different base frequencies. The TDEM receiver measures and records the decay of the vertical magnetic field through a receiver coil placed at the center of the non-grounded transmitter loop. Receiver coils with effective areas of 100 m^2 and 1,000 m^2 were utilized at base frequencies of 3 Hz and 30 Hz. During data acquisition numerous transient decays are collected with the receiver for each sounding. Readings were acquired at several receiver gains with opposite receiver polarities for each sounding location. The readings were stored in a DAS-54 solid state data logger, and were nightly transferred to a personal computer for processing. A technical note is given in Appendix A which describes and illustrates the principles of TDEM.


KEALAKEKUA
Captain Cook
Makolehale 2
VABM 2277
BOUNDARY
ROCK WALL
Approximate Property Boundary
APPROXIMATE
Cooks Heiau
Umis Well
Pali Kapu
Keoua
Cook Point
COOKS MONUMENT
Kaawaloa
VABM 36
Heiau
BM 1541
Cem
KEALAKEKUA BAY
Kealakekua Bay Park
Hikiau Heiau
Napoopoo
Kapahukapu
Manini Beach
NAPOOPOO PARK
Kepuhi
Kahauloa
Cemetery
Keawelki
Well
Water Tank
Coffee Mill
Napoopoo School
VABM 1347
1 Sounding Location
Geoelectric Cross Section
HAWAIIAN ISLANDS
HAWAII
QUADRANGLE LOCATION
1 MILE
7000 FEET
BLACKHAWK GEOSCIENCES, INC.
GEOPHYSICAL SURVEY LOCATION MAP
Royal Coast Development Corp.
Tom Nance Water Res. Engr.
PROJECT NO: 60042
Figure 2-1

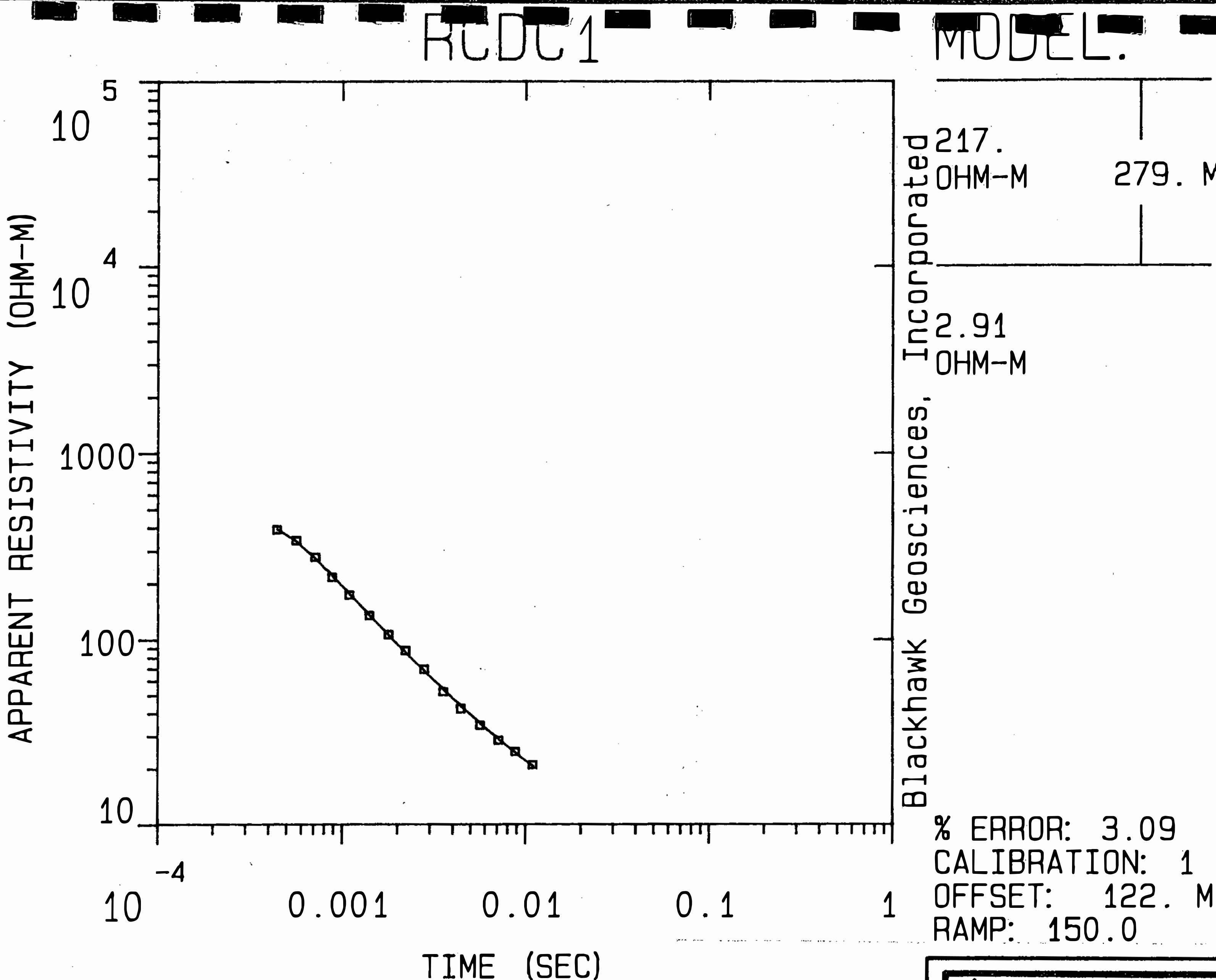
3.0 DATA PROCESSING

The field data acquired each day was transferred from the DAS-54 data logger to a personal computer. The data for each sounding location is edited and combined (both 3 Hz and 30 Hz frequencies) to produce a transient decay curve. This decay curve is transformed into an apparent resistivity curve, which is entered into an Automatic Ridge Regression Transient Inversion Program (ARRTI). From the apparent resistivity curve a one-dimensional model of resistivities and thicknesses is calculated.

The inversion program requires an initial estimate of the geoelectric section, including the number of layers, and the resistivities and thicknesses of each of the layers. The program then adjusts these parameters so that the model curve converges to best fit the curve formed by the field data set. The inversion program does not change the total number of layers within the model, but allows all other parameters to float freely.

An example data set is given in Figures 3-1 and 3-2 for sounding RCDC1. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 lists in column 4 the error between measured and computed data in each time gate.

The apparent resistivity curves and data sheets for all soundings are contained in Appendix B.



BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET
SOUNDING RCDC1
Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042 **Figure 3-1**

RCDC1

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		259.1	850.0		
217.05	279.4	-20.3	-66.6	1.3	1.3
2.91					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	4.43E-04	3.90E+02	3.94E+02	-1.152	
2	5.64E-04	3.41E+02	3.35E+02	1.765	
3	7.13E-04	2.78E+02	2.72E+02	2.056	
4	8.81E-04	2.17E+02	2.21E+02	-1.927	
5	1.10E-03	1.74E+02	1.76E+02	-1.344	
6	1.41E-03	1.35E+02	1.35E+02	-0.493	
7	1.80E-03	1.07E+02	1.06E+02	1.030	
8	2.22E-03	8.74E+01	8.49E+01	2.907	
9	2.80E-03	6.94E+01	6.76E+01	2.718	
10	3.55E-03	5.25E+01	5.38E+01	-2.456	
11	4.43E-03	4.24E+01	4.38E+01	-3.097	
12	5.64E-03	3.45E+01	3.53E+01	-2.249	
13	7.13E-03	2.86E+01	2.89E+01	-1.226	
14	8.81E-03	2.48E+01	2.44E+01	1.712	
15	1.10E-02	2.11E+01	2.06E+01	2.287	

R: 122. X: 0. Y: 122. DL: 243. REQ: 136. CF: 1.0000
CLHZ ARRAY, 15 DATA POINTS, RAMP: 150.0 MICROSEC, DATA: RCDC1
0709 001N 001E Z OPR XTL H 4 8+100
Ch.21 = 0.15 Ch.22 = 0.089 Ch.23 = 17.5 Ch.24 =
RMS LOG ERROR: 1.32E-02, ANTILOG YIELDS 3.0872 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.96		
P 2	-0.04	0.91	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SET
SOUNDING RCDC1
Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042 **Figure 3-2**

4.0 INTERPRETATION RESULTS

4.1 GENERAL

From individual soundings the results of the interpretations are the resistivity layering as a function of depth. Where measurements are taken relatively close together, the results of these individual soundings can be plotted to construct a geoelectric cross-section along a line. Of the six soundings acquired over the area, five were incorporated in a geoelectric cross-section. Figure 2-1 shows the geoelectric cross-section and the individual sounding locations. Rather than projecting sounding 1 on a linear cross-section through soundings 3 through 5, a bend is incorporated on the section.

To infer from the geoelectric cross-sections geologic and geohydrologic information, characteristic ranges of resistivities are assigned to known local geologic and geohydrologic units. The assigned resistivity ranges for the various units expected in the survey area are shown in Figure 4-1. An overlap occurs between the resistivity ranges, and the most extensive overlap is found between the ash flows, weathered volcanics or intrusives, and the dry unweathered or mainly fresh water saturated volcanics. In most cases these two units can be separated by their resistivity value in ohm-m and their relative depth of occurrence in the section. Within the survey area zones of lower resistivities were detected near or above sea level in some of the TDEM soundings. These zones of lower resistivity could be caused by a combination of several factors which affect the resistivity of the hydrogeologic section. These factors are changes in lithology, porosity, and salinity which influence formation resistivity.

Where a very conductive layer (< 5 ohm-m) is detected below sea level, the layer is expected to be caused by salt water saturated volcanics. Static water levels (heads) can subsequently be calculated from these soundings by using the Ghyben-Herzberg principle. This principle states that under conditions of static equilibrium, for every foot of fresh water above sea level there will be about forty feet of fresh water below sea level. An illustration of the Ghyben-Herzberg principle is given in Figure 4-2. This principle, however, assumes static equilibrium and may not apply to TDEM soundings in close proximity to ground water damming structures (i.e., dikes, rifts, etc.).

4.2 GEOELECTRIC CROSS-SECTION

Figure 4-3 shows the results of five TDEM soundings which are presented as a roughly west-to-east-to-north trending geoelectric cross-section. Within the section layers with similar resistivities have been linked together.

Similar two layer sequences are interpreted in the geoelectric section for soundings 1, 2 and 3. The upper layer exhibits resistivities ranging from 217 to 391 ohm-m and is interpreted to represent unweathered volcanics. Where this layer occurs below sea level it is expected to be saturated with fresh-brackish water. The lower layer of these three soundings show resistivities between 2.9 to 4.6 ohm-m, this layer is interpreted to represent salt water saturated volcanics. Assuming static equilibrium exists, the elevation of the static water level (head) can be calculated using the Ghyben-Herzberg principle. The approximate thickness of the fresh-brackish water lens was found to vary below these soundings from 46 ft at sounding 3 to 127 ft at sounding 2.

In the geoelectric section below soundings 4 and 5 a layer with a resistivity of < 5 ohm-m is not observed within the effective exploration depth of the measurements (about -500 ft elevation). At depth in soundings 4 and 5 a lower layer exhibits a resistivity of 7 to 12 ohm-m, respectively, which occurs above or nearly at sea level. Where such distinct changes in geoelectric sections are observed, i.e., between soundings 2 and 4, the data are expected to be affected by lateral changes within the subsurface. This discontinuity may be the result of several geologic factors and is interpreted as ash flows, weathered volcanics, or intrusives.

Similar discontinuities have previously been observed in other areas on the island of Hawaii, and from measurements at elevations above such discontinuities, often the potential for significant fresh ground water resources was inferred. Because of the presence of culture, TDEM measurements could not be made at higher elevations than soundings 4 and 5. In fact, an attempt was made at sounding 6, but this data was distorted by culture. The structure inferred below soundings 4 and 5 can have a number of causes such as ash flows and/or intrusives. If these structures are also hydrogeologic barriers, then the potential for fresh water may exist above them.

4.3 HYDROGEOLOGIC INTERPRETATION

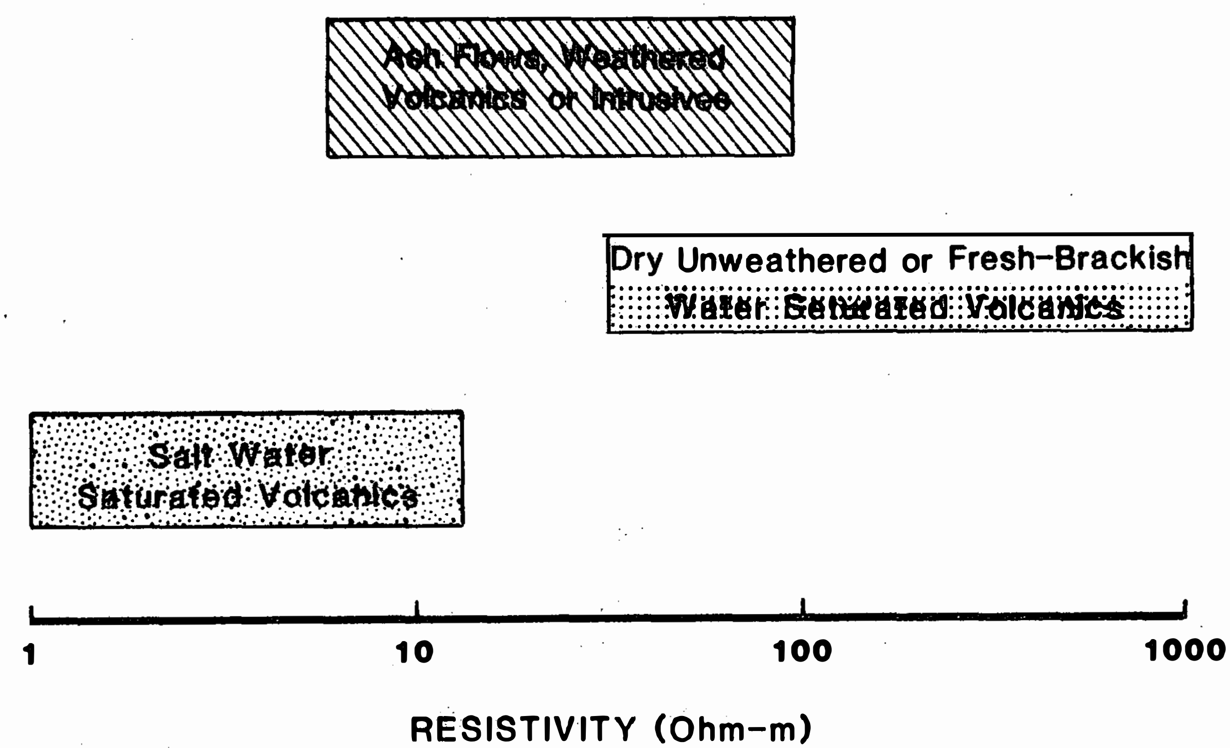
Figure 4-4 shows the geophysical interpretation map for the TDEM survey. Beneath soundings 1, 2 and 3 fresh-brackish water resources are expected to exist in the basal mode. Table 4-1 lists the thickness of the fresh-brackish water lens calculated from the elevation of the salt water interface derived from the TDEM soundings.

Below soundings 4 and 5, ground water conditions are expected to be controlled by geologic structures. Approximate thickness of fresh water resources cannot be computed from the Ghyben-Herzberg principle for these two soundings.

Because of the limited TDEM data density in the area, the boundary between basal mode ground water and structurally controlled ground water could not be determined. Unfortunately, an attempt to obtain data at elevation above soundings 4 and 5 was not successful due to culture (power lines, pipelines, buildings).

Table 4-1. **<u>Hydrogeologic information derived from TDEM soundings</u>**

Sounding #	Surface Elevation (ft)	Approximate Thickness of Fresh/Brackish Water Lens (ft)
1	850	66
2	1040	127
3	1000	46
4	1190	Structure Controlled
5	1180	Structure Controlled
6	1630	Distorted Data



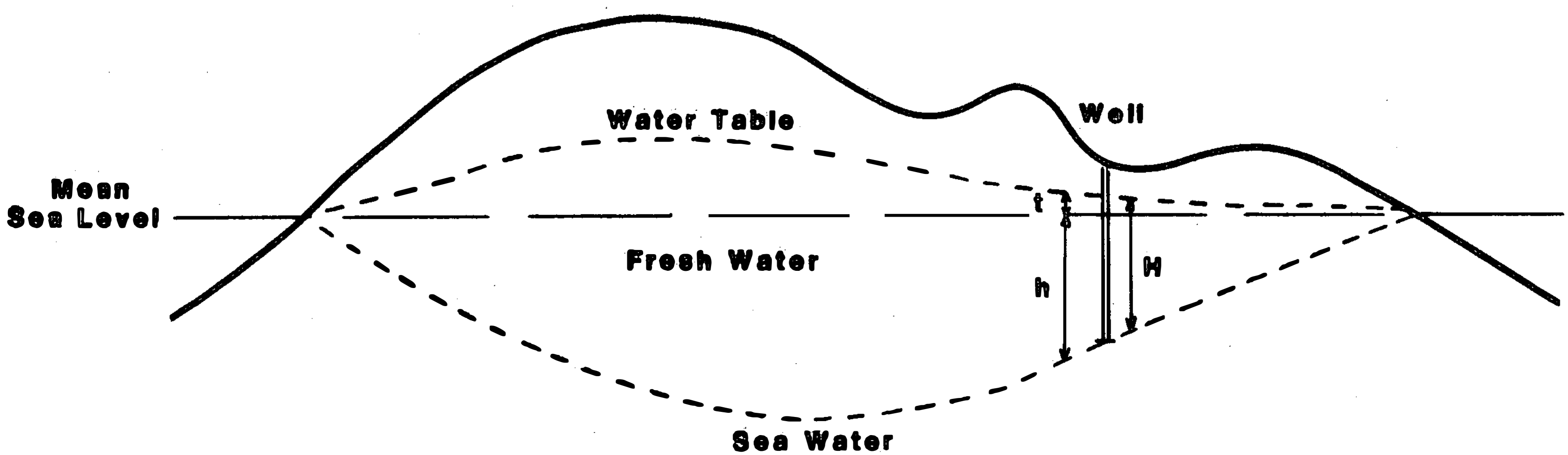
BLACKHAWK GEOSCIENCES, INC.

CHARACTERISTIC
RESISTIVITY RANGES

Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042

Figure 4-1



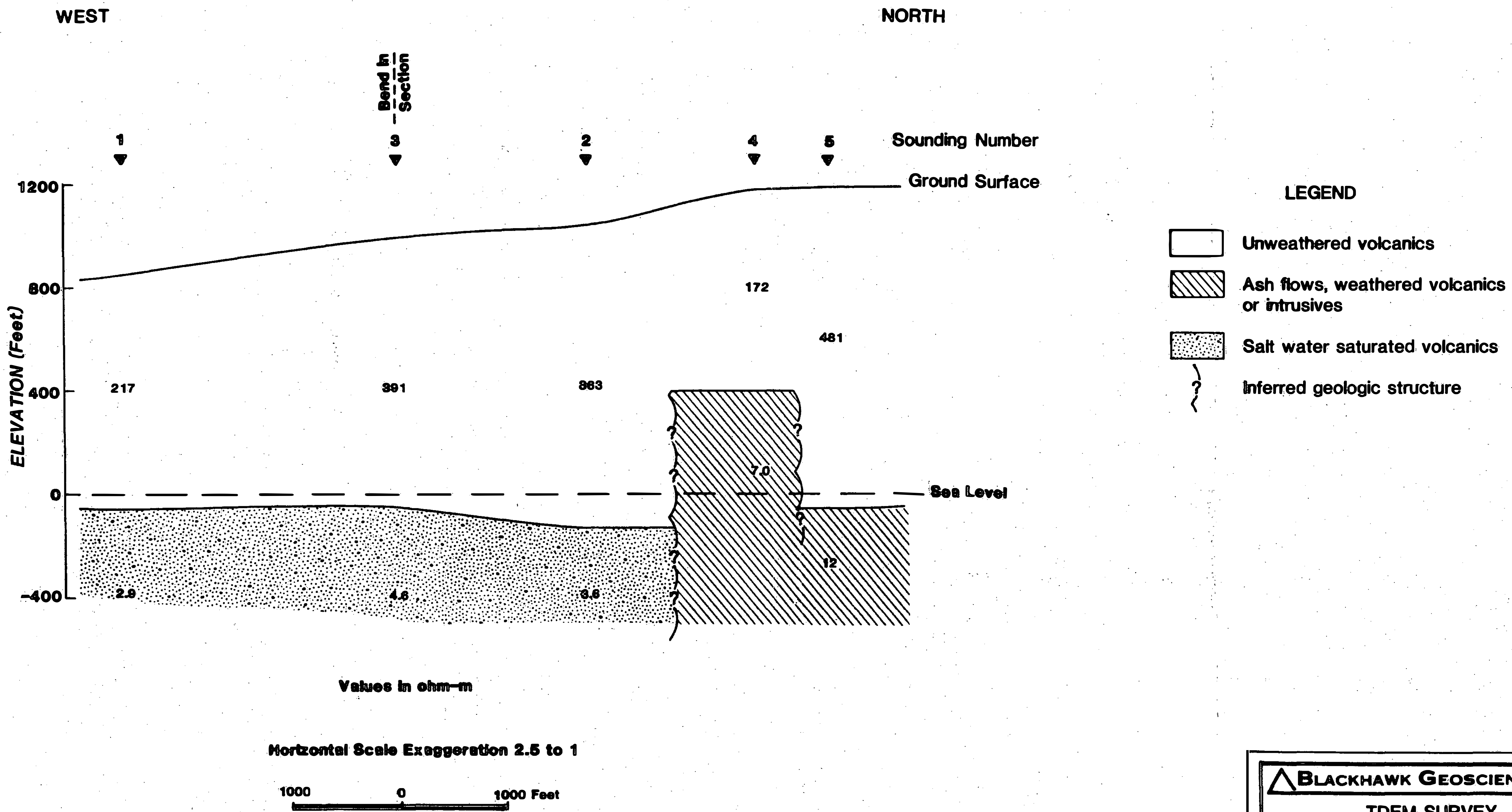
$t = 1/40\ (h)$

FROM: HERZBERG

BLACKHAWK GEOSCIENCES, INC.

Illustration of the
Ghyben-Herzberg Principle
Royal Coast Development Corp.
Tom Nance Water Res. Engr.

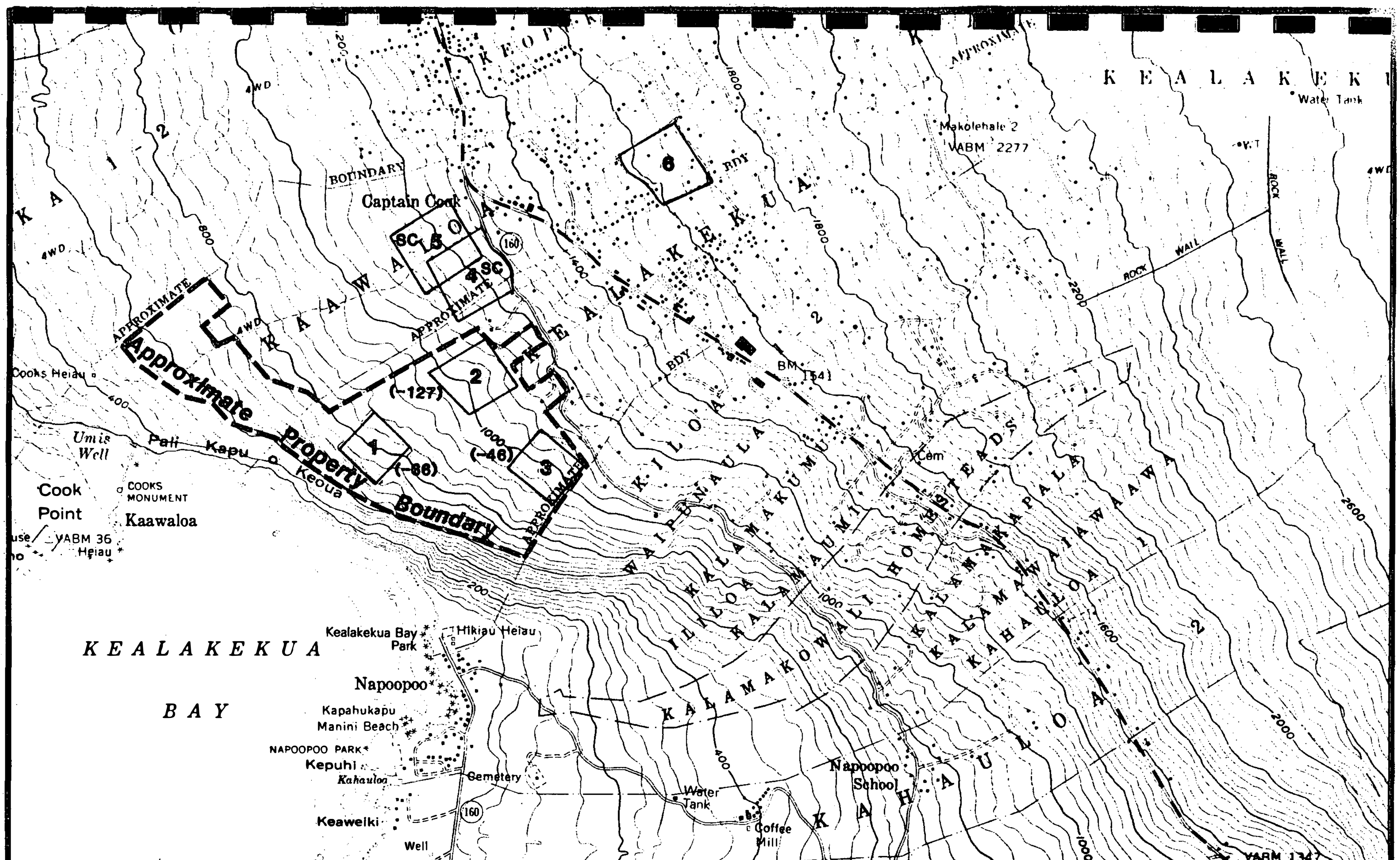
PROJECT NO: 90042 Figure 4-2

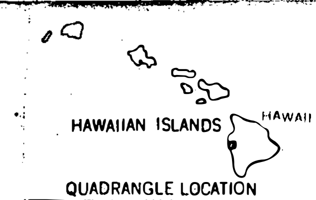


BLACKHAWK GEOSCIENCES, INC.

TDEM SURVEY
GEOELECTRIC CROSS SECTION
Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042 Figure 4-3





SC Structure Controlled

1 Sounding Location

(-66) Approximate Elevation of Top of Salt Water Interface

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

N

BLACKHAWK GEOSCIENCES, INC.

TDEM INTERPRETATION MAP

Royal Coast Development Corp.
Tom Nance Water Res. Engr.

PROJECT NO: 90042 **Figure 4-4**

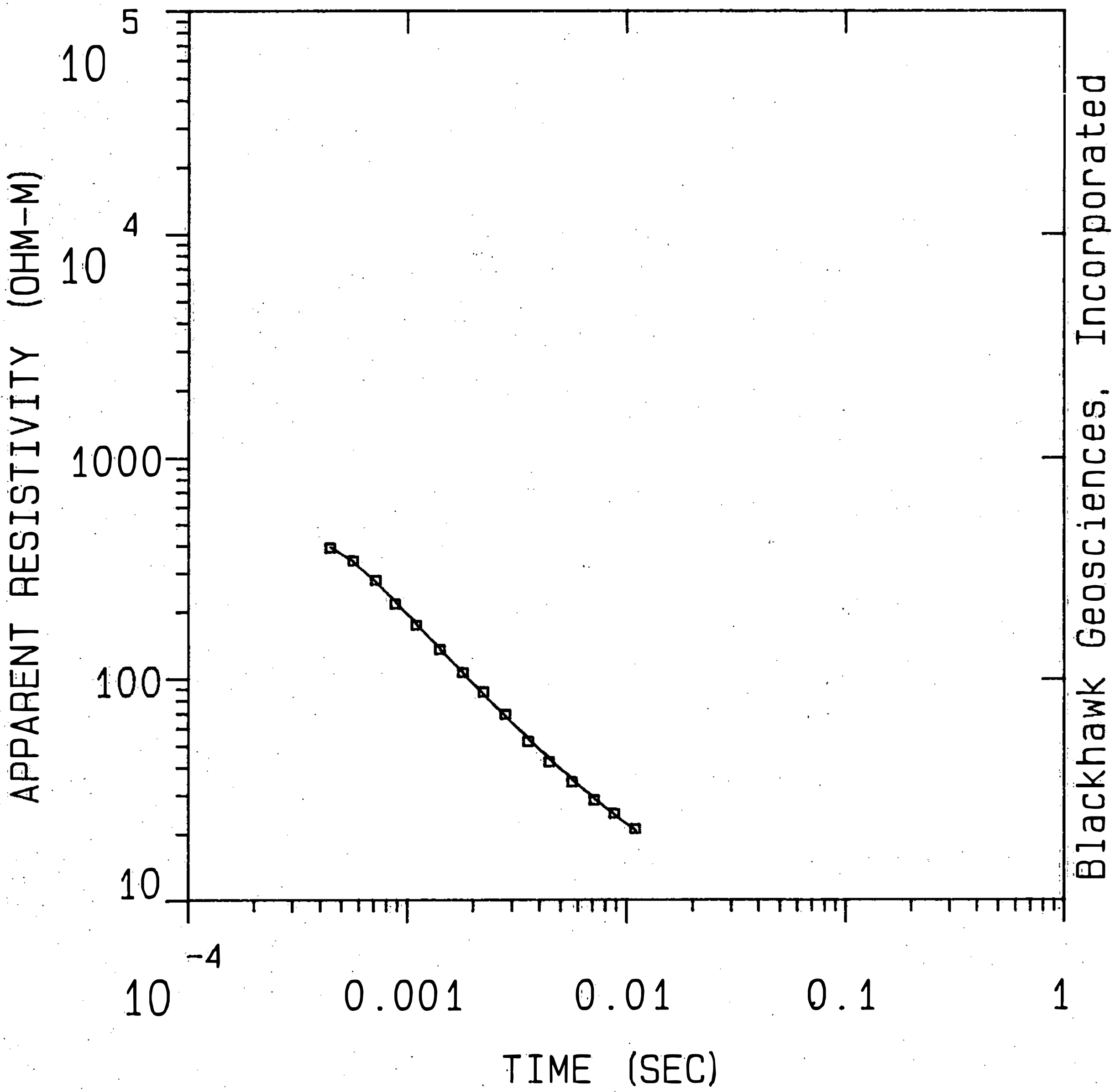
5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the TDEM survey are summarized in Figure 4-4. In this figure, beneath soundings 1, 2 and 3, ground water resources are expected to be present in the basal mode. From the elevation of the salt water interface derived from the TDEM soundings, and assuming validity of the Ghyben-Herzberg principle, the fresh-brackish ground water resources are expected to be marginal. The thickness of the basal fresh-brackish water lens is expected to vary from about 46 ft to 127 ft in the area.

Beneath soundings 4 and 5, the geoelectric section appears to indicate the existence of a structure, and this structure might control ground water. If this is the case, the potential for dike-confined water may exist above soundings 4 and 5 at higher elevation. An attempt was made to acquire data above the 1,600 ft elevation level, but this proved unsuccessful due to limited property access and excessive cultural noise, which resulted in a distorted TDEM measurement.

The accuracy in determining the depth to the salt water saturated interface has previously been estimated to be about ± 5% of the total depth measured.

RCDC1



MODEL:

217. OHM-M — 279. M

2.91 OHM-M

% ERROR: 3.09
CALIBRATION: 1
OFFSET: 122. M
RAMP: 150.0

RCDC1

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		259.1	850.0		
217.05	279.4	-20.3	-66.6	1.3	1.3
2.91					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	4.43E-04	3.90E+02	3.94E+02	-1.152	
2	5.64E-04	3.41E+02	3.35E+02	1.765	
3	7.13E-04	2.78E+02	2.72E+02	2.056	
4	8.81E-04	2.17E+02	2.21E+02	-1.927	
5	1.10E-03	1.74E+02	1.76E+02	-1.344	
6	1.41E-03	1.35E+02	1.35E+02	-0.493	
7	1.80E-03	1.07E+02	1.06E+02	1.030	
8	2.22E-03	8.74E+01	8.49E+01	2.907	
9	2.80E-03	6.94E+01	6.76E+01	2.718	
10	3.55E-03	5.25E+01	5.38E+01	-2.456	
11	4.43E-03	4.24E+01	4.38E+01	-3.097	
12	5.64E-03	3.45E+01	3.53E+01	-2.249	
13	7.13E-03	2.86E+01	2.89E+01	-1.226	
14	8.81E-03	2.48E+01	2.44E+01	1.712	
15	1.10E-02	2.11E+01	2.06E+01	2.287	

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Ch.21 = 0.15 Ch.22 = 0.089 Ch.23 = 17.5 Ch.24 =
RMS LOG ERROR: 1.32E-02, ANTILOG YIELDS 3.0872 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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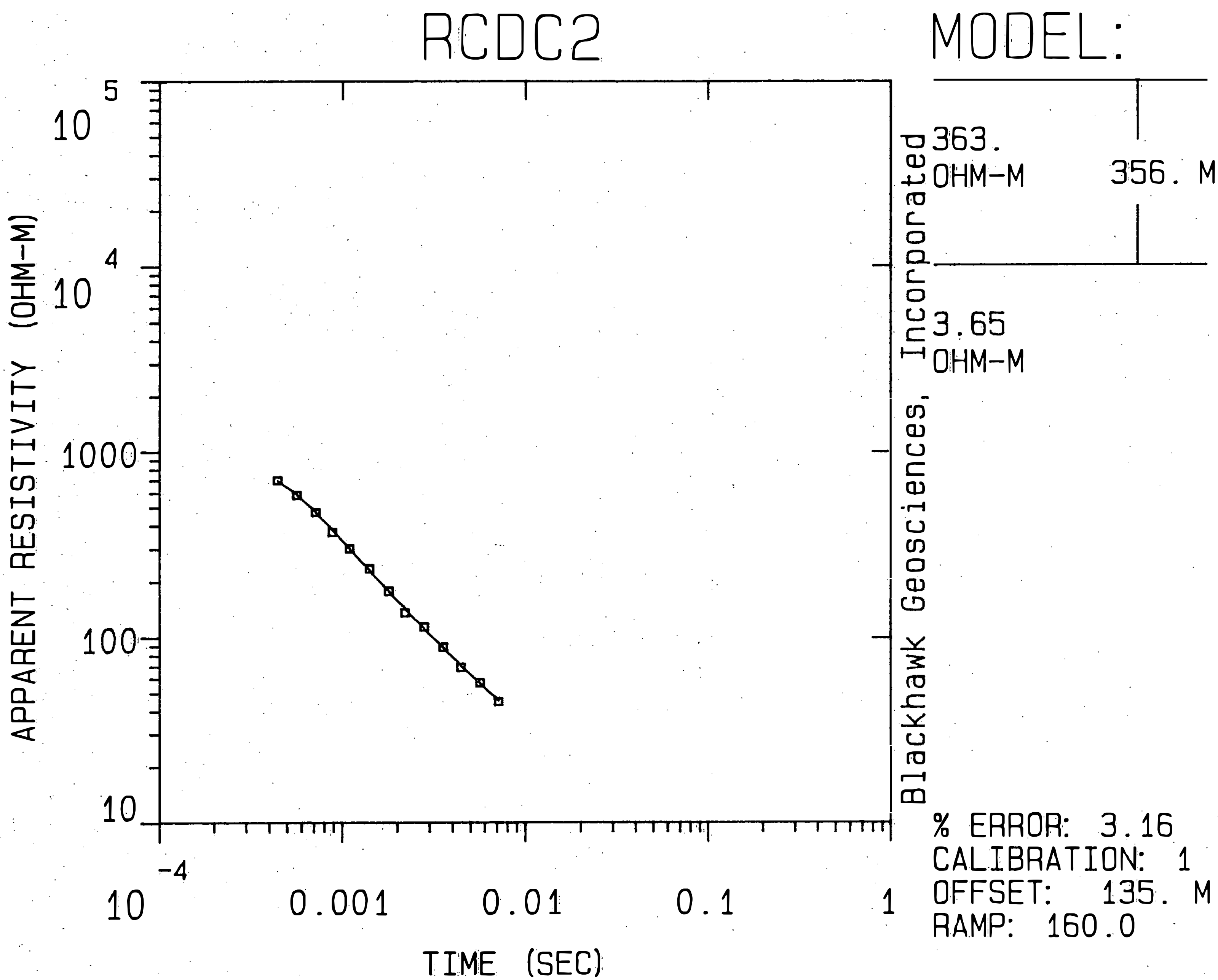
P 1	0.96		
P 2	-0.04	0.91	
T 1	0.00	0.00	1.00


RCDC2
MODEL:
APPARENT RESISTIVITY (OHM-M)
10 5
10 4
1000
100
10
10 -4
0.001
0.01
0.1
1
TIME (SEC)
Blackhawk Geosciences, Incorporated
363.
OHM-M
356. M
3.65
OHM-M
% ERROR: 3.16
CALIBRATION: 1
OFFSET: 135. M
RAMP: 160.0

RCDC2

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		317.0	1040.0		
363.45	355.8	-38.8	-127.2	1.0	1.0
3.65					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	4.43E-04	7.00E+02	6.96E+02	0.506	
2	5.64E-04	5.83E+02	5.84E+02	-0.317	
3	7.13E-04	4.70E+02	4.70E+02	0.061	
4	8.81E-04	3.68E+02	3.78E+02	-2.596	
5	1.10E-03	3.01E+02	2.99E+02	0.621	
6	1.41E-03	2.35E+02	2.28E+02	2.870	
7	1.80E-03	1.78E+02	1.76E+02	0.780	
8	2.20E-03	1.36E+02	1.42E+02	-4.267	
9	2.80E-03	1.15E+02	1.11E+02	3.246	
10	3.55E-03	8.91E+01	8.77E+01	1.578	
11	4.43E-03	6.92E+01	7.08E+01	-2.164	
12	5.64E-03	5.72E+01	5.65E+01	1.355	
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LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

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"F" MEANS FIXED PARAMETER

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T 1	0.00	0.00	1.00
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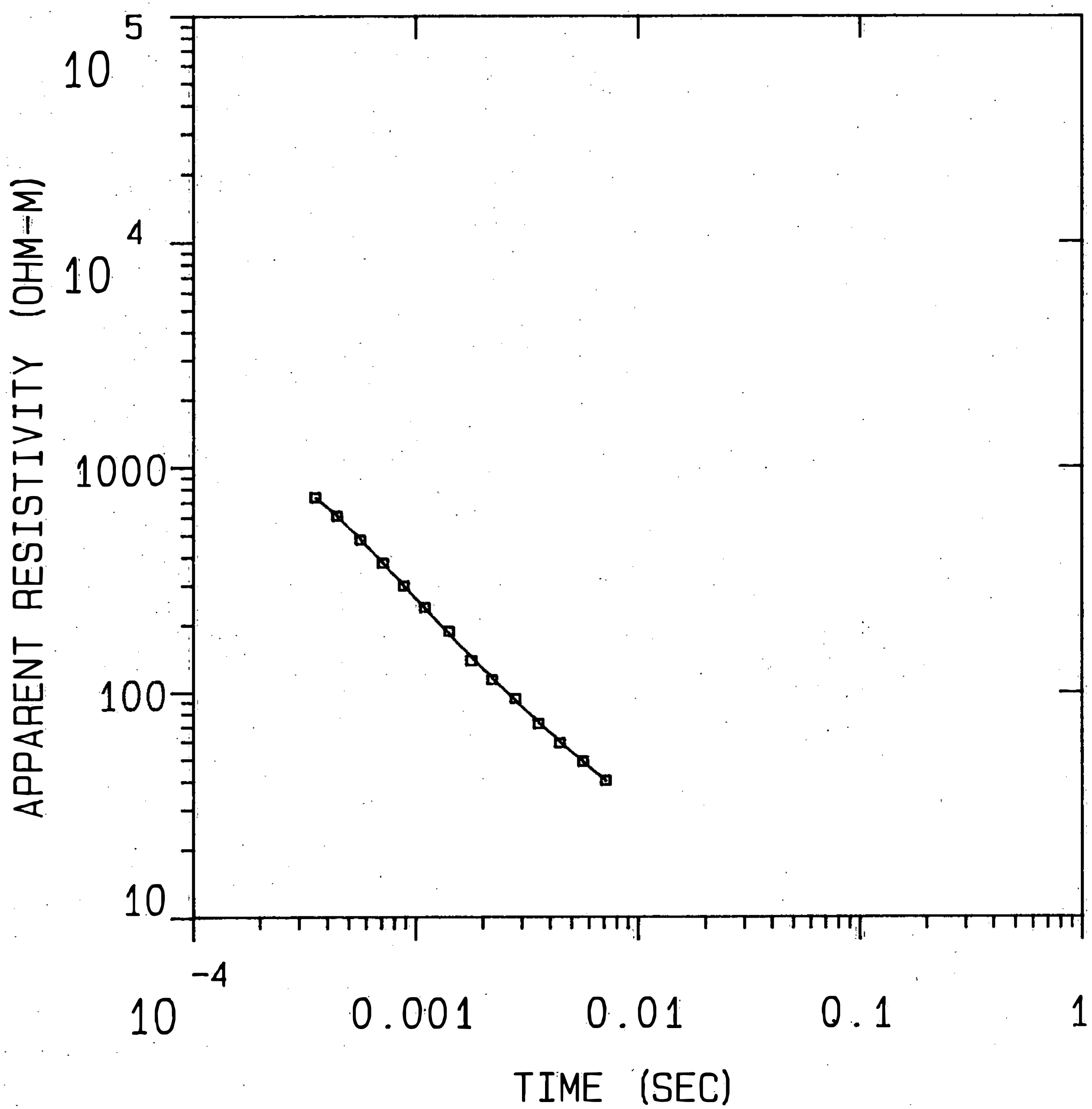


Blackhawk Geosciences, Incorporated

MODEL:

391. OHM-M 319. M

4.64 OHM-M

% ERROR: 2.46
CALIBRATION: 1
OFFSET: 134. M
RAMP: 160.0

RCDC3

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		304.8	1000.0		
390.93	318.8	-14.0	-45.8	0.8	0.8
4.64					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	3.55E-04	7.34E+02	7.34E+02	0.038	
2	4.43E-04	6.09E+02	6.09E+02	-0.029	
3	5.64E-04	4.77E+02	4.80E+02	-0.558	
4	7.13E-04	3.76E+02	3.75E+02	0.334	
5	8.81E-04	2.98E+02	2.99E+02	-0.057	
6	1.10E-03	2.38E+02	2.36E+02	0.853	
7	1.41E-03	1.87E+02	1.81E+02	3.039	
8	1.77E-03	1.38E+02	1.43E+02	-3.679	
9	2.20E-03	1.14E+02	1.15E+02	-1.493	
10	2.80E-03	9.36E+01	9.12E+01	2.674	
11	3.55E-03	7.21E+01	7.30E+01	-1.124	
12	4.43E-03	5.91E+01	5.98E+01	-1.1[illegible]1	
13	5.64E-03	4.89E+01	4.86E+01	0.767	
14	7.13E-03	4.03E+01	4.01E+01	0.466	

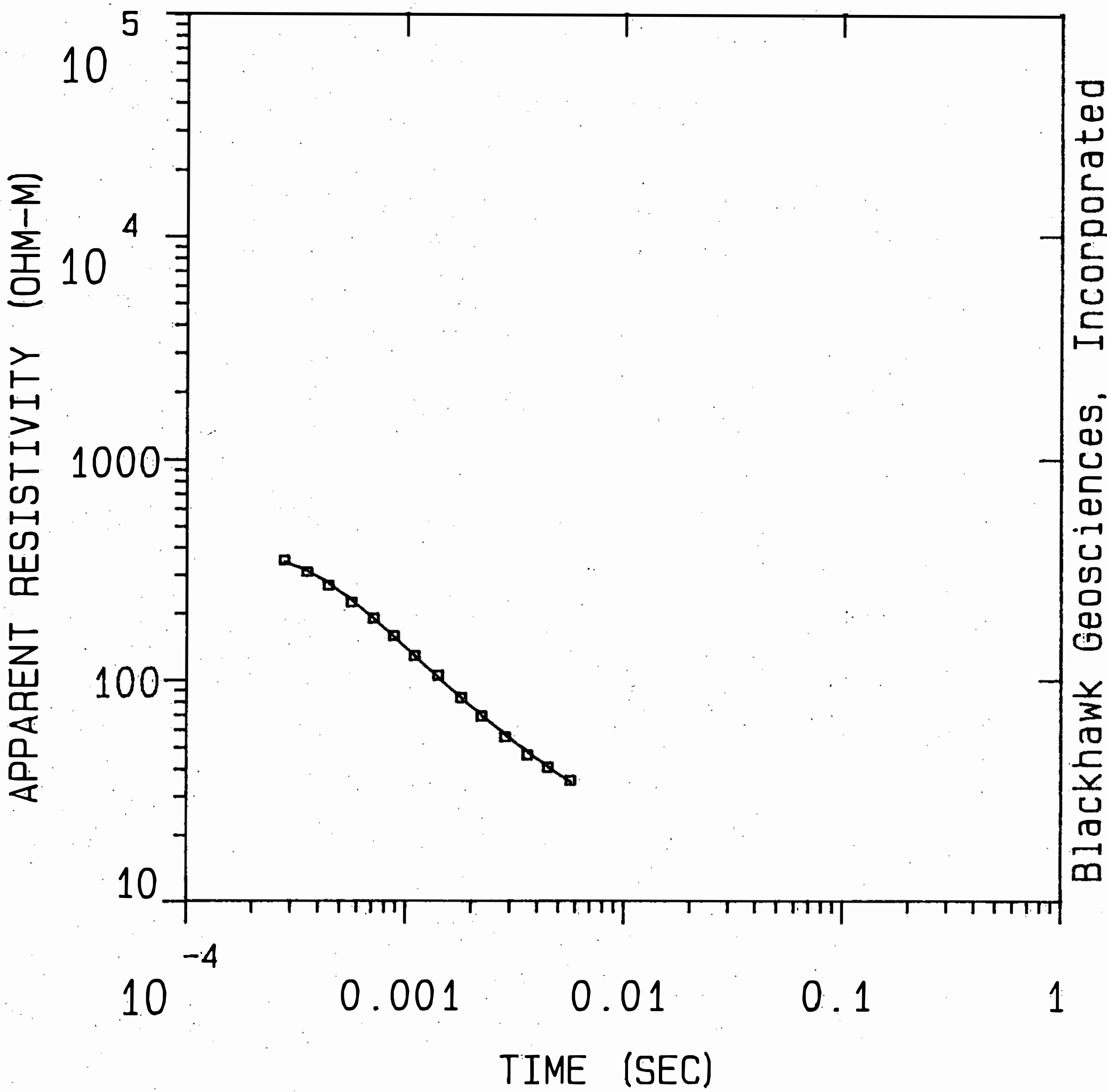
R: 134. X: 0. Y: 134. DL: 269. REQ: 149. CF: 1.0000
TDHZ ARRAY, 14 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: RCDC3
0809 001N 003E Z OPR XTL L 6 10+100
Ch.21 = 0.16 Ch.22 = 0.89 Ch.23 = 16 Ch.24 = 72
RMS LOG ERROR: 1.05E-02, ANTILOG YIELDS 2.4583 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	T 1
P 1	0.91		
P 2	-0.07	0.87	
T 1	0.00	0.00	1.00

RCDC4



MODEL:

172.
OHM-M
241. M

7.01
OHM-M

% ERROR: 2.54
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

RCDC4

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		362.7	1190.0		
171.96	240.5	122.2	400.9	1.4	1.4
7.01					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	3.49E+02	3.44E+02	1.567	
2	3.55E-04	3.09E+02	3.11E+02	-0.529	
3	4.43E-04	2.68E+02	2.73E+02	-1.835	
4	5.64E-04	2.24E+02	2.29E+02	-1.919	
5	7.13E-04	1.90E+02	1.88E+02	0.954	
6	8.81E-04	1.58E+02	1.56E+02	1.433	
7	1.10E-03	1.28E+02	1.28E+02	0.245	
8	1.41E-03	1.05E+02	1.02E+02	2.643	
9	1.80E-03	8.33E+01	8.29E+01	0.446	
10	2.22E-03	6.90E+01	6.94E+01	-0.576	
11	2.85E-03	5.58E+01	5.69E+01	-1.927	
12	3.60E-03	4.62E+01	4.77E+01	-3.052	
13	4.49E-03	4.08E+01	4.07E+01	0.108	
14	5.70E-03	3.56E+01	3.47E+01	2.357	

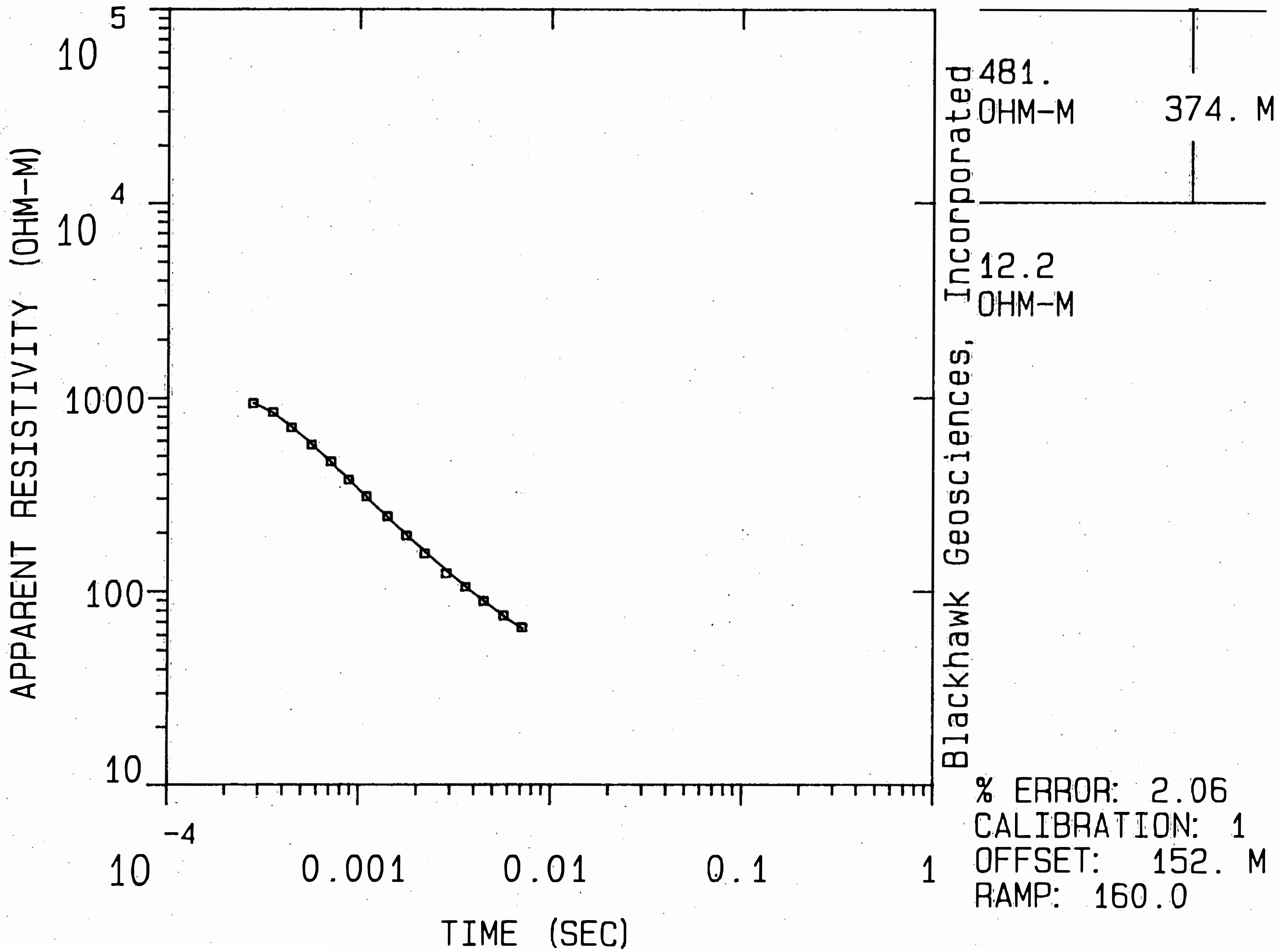
R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
TDHZ ARRAY, 14 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: RCDC4
1409 001N 004E Z OPR XTL L 5 8-100
Ch.21 = 0.16 Ch.22 = 0.089 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 1.09E-02, ANTILOG YIELDS 2.5365 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	P 2	T 1
P 1	1.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00

RCDC5


MODEL:
481.
OHM-M
374. M
12.2
OHM-M
Blackhawk Geosciences, Incorporated
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-4}
0.001
0.01
0.1
1
TIME (SEC)
% ERROR: 2.06
CALIBRATION: 1
OFFSET: 152. M
RAMP: 160.0

RCDC5

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		359.7	1180.0		
481.27	374.0	-14.4	-47.1	0.8	0.8
12.17					

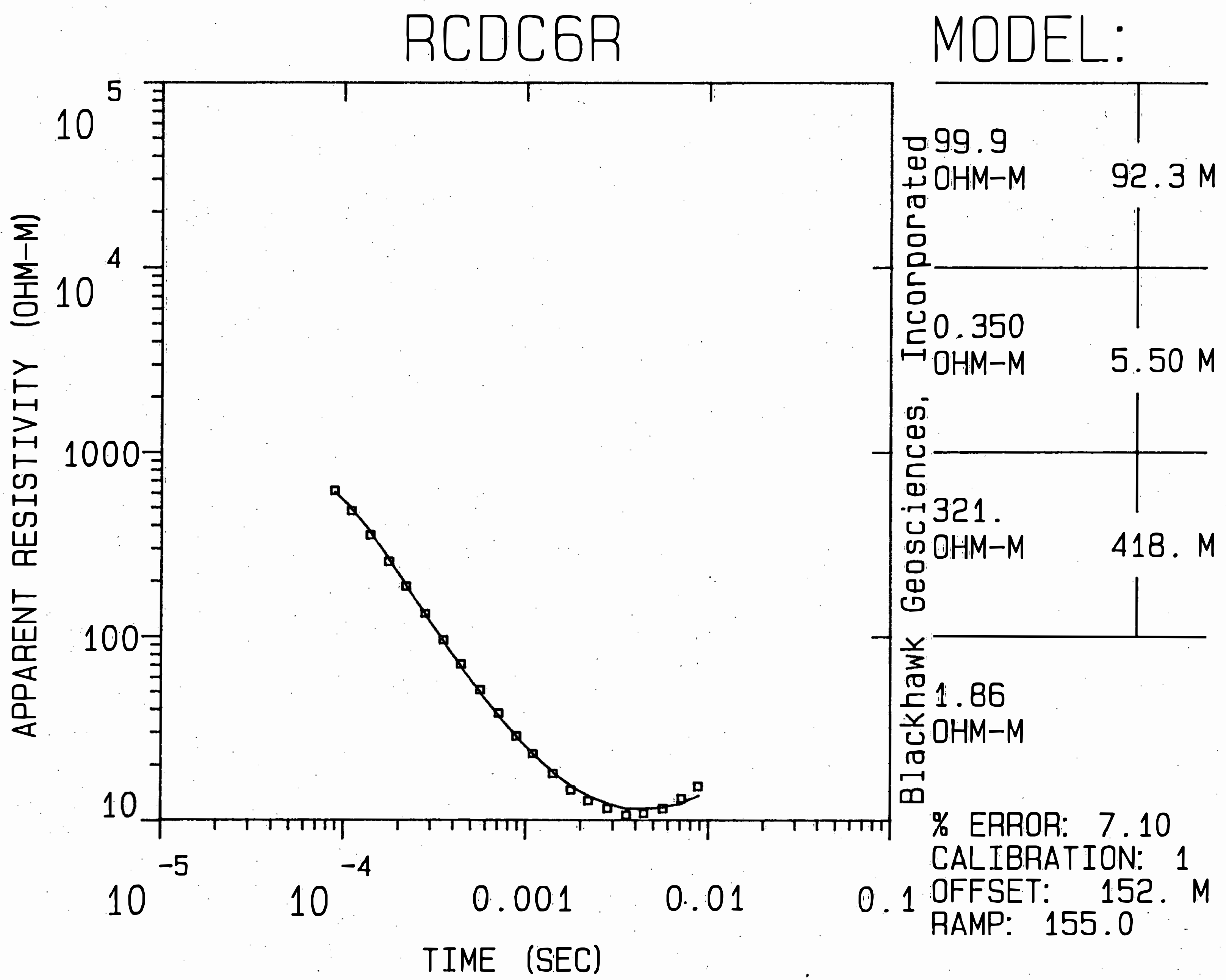
	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	9.37E+02	9.45E+02	-0.815	
2	3.55E-04	8.42E+02	8.30E+02	1.442	
3	4.43E-04	7.01E+02	7.06E+02	-0.632	
4	5.64E-04	5.69E+02	5.72E+02	-0.540	
5	7.13E-04	4.64E+02	4.59E+02	1.217	
6	8.81E-04	3.74E+02	3.74E+02	0.039	
7	1.10E-03	3.06E+02	3.02E+02	1.225	
8	1.41E-03	2.42E+02	2.38E+02	1.564	
9	1.77E-03	1.92E+02	1.93E+02	-0.351	
10	2.20E-03	1.56E+02	1.59E+02	-2.121	
11	2.85E-03	1.23E+02	1.28E+02	-3.207	
12	3.60E-03	1.05E+02	1.06E+02	-0.125	
13	4.49E-03	8.91E+01	8.90E+01	0.106	
14	5.70E-03	7.53E+01	7.48E+01	0.574	
15	7.13E-03	6.54E+01	6.43E+01	1.810	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
TDHZ ARRAY, 15 DATA POINTS, RAMP: 160.0 MICROSEC, DATA: RCDC5
1609 001N 005E Z OPR XTL L 5 10+100
Ch.21 = 0.16 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 92
RMS LOG ERROR: 8.85E-03, ANTILOG YIELDS 2.0587 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00		
P 2	0.00	1.00	
T 1	0.00	0.00	1.00
	P 1	P 2	T 1


RCDC6R
MODEL:
10^5
10^4
1000
100
10
APPARENT RESISTIVITY (OHM-M)
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
99.9
OHM-M
92.3 M
0.350
OHM-M
5.50 M
321.
OHM-M
418. M
1.86
OHM-M
% ERROR: 7.10
CALIBRATION: 1
OFFSET: 152. M
RAMP: 155.0

RCDC6R

MODEL: 4 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		496.8	1630.0		
99.92	92.3	404.5	1327.1	0.9	0.9
0.35	5.5	399.0	1309.0	15.7	16.6
320.75	417.7	-18.7	-61.5	1.3	17.9
1.86					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	6.14E+02	6.06E+02	1.352	
2	1.10E-04	4.76E+02	4.92E+02	-3.108	
3	1.40E-04	3.53E+02	3.64E+02	-3.217	
4	1.77E-04	2.54E+02	2.61E+02	-2.933	
5	2.20E-04	1.87E+02	1.88E+02	-0.199	
6	2.80E-04	1.33E+02	1.31E+02	1.681	
7	3.55E-04	9.57E+01	9.29E+01	2.958	
8	4.43E-04	7.08E+01	6.78E+01	4.341	
9	5.64E-04	5.12E+01	4.91E+01	4.322	
10	7.13E-04	3.82E+01	3.66E+01	4.309	
11	8.90E-04	2.86E+01	2.83E+01	1.031	
12	1.10E-03	2.30E+01	2.28E+01	0.855	
13	1.41E-03	1.79E+01	1.82E+01	-1.280	
14	1.77E-03	1.46E+01	1.53E+01	-4.592	
15	2.20E-03	1.28E+01	1.35E+01	-5.525	
16	2.80E-03	1.16E+01	1.23E+01	-5.613	
17	3.55E-03	1.07E+01	1.15E+01	-7.265	
18	4.43E-03	1.09E+01	1.15E+01	-5.389	
19	5.64E-03	1.16E+01	1.19E+01	-1.968	
20	7.13E-03	1.32E+01	1.24E+01	6.245	
21	8.81E-03	1.54E+01	1.37E+01	11.718	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 21 DATA POINTS, RAMP: 155.0 MICROSEC, DATA: RCDC6R
1709 001N 006E Z OPR XTL L 3 10+100
Ch.21 = 0.155 Ch.22 = 0.89 Ch.23 = 15 Ch.24 = 9
RMS LOG ERROR: 2.98E-02, ANTILOG YIELDS 7.0956 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.87						
P 2	-0.01	0.53					
P 3	0.00	0.00	0.00				
P 4	-0.01	0.00	0.00	0.00			
T 1	0.00	0.03	0.00	0.00	0.99		
T 2	0.00	-0.48	-0.01	0.01	0.03	0.49	
T 3	-0.02	-0.01	0.00	0.00	-0.01	0.02	0.01
	P 1	P 2	P 3	P 4	T 1	T 2	T 3